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IV. *On Nebulous Stars, properly so called.**By William Herschel, LL.D. F. R. S.*

Read February 10, 1791.

IN one of my late examinations of a space in the heavens, which I had not reviewed before, I discovered *a star of about the 8th magnitude, surrounded with a faintly luminous atmosphere, of a considerable extent.* The phænomenon was so striking that I could not help reflecting upon the circumstances that attended it, which appeared to me to be of a very instructive nature, and such as may lead to inferences which will throw a considerable light on some points relating to the construction of the heavens.

Cloudy or nebulous stars have been mentioned by several astronomers; but this name ought not to be applied to the objects which they have pointed out as such; for, on examination, they proved to be either mere clusters of stars, plainly to be distinguished with my large instruments, or such nebulous appearances as might be reasonably supposed to be occasioned by a multitude of stars at a vast distance. The milky way itself, as I have shewn in some former Papers, consists intirely of stars, and by imperceptible degrees I have been led on from the most evident congeries of stars to other groups in which the lucid points were smaller, but still very plainly to be seen; and from them to such wherein they could but barely be suspected, till I arrived at last to spots in which no trace of
a star

a star was to be discerned. But then the gradations to these latter were by such well-connected steps as left no room for doubt but that all these phænomena were equally occasioned by stars, variously dispersed in the immense expanse of the universe.

When I pursued these researches, I was in the situation of a natural philosopher who follows the various species of animals and insects from the height of their perfection down to the lowest ebb of life; when, arriving at the vegetable kingdom, he can scarcely point out to us the precise boundary where the animal ceases and the plant begins; and may even go so far as to suspect them not to be essentially different. But recollecting himself, he compares, for instance, one of the human species to a tree, and all doubt upon the subject vanishes before him. In the same manner we pass through gentle steps from a coarse cluster of stars, such as the Pleiades, the Præsepe, the milky way, the cluster in the Crab, the nebula in Hercules, that near the preceding hip of Bootes (*a*), the 17th, 38th, 41st of the 7th class of my Catalogues (*b*), the 10th, 20th, 35th of the 6th class (*c*), the 33d, 48th, 213th of the 1st (*d*), the 12th,

(*a*) RA. 13 h. 27' 40". PD. 60° 2'. The places of all the objects mentioned in this Paper are not brought to the present time, but given as they were calculated from the best observations I have made of them; the change in their situation arising from the lapse of a few years is too trifling to be any hindrance to our finding them very easily.

			h.				
(<i>b</i>)	VII.	17.	RA.	7	9	45.	PD. 114 34.
		38.		6	53	16.	88 37.
		41.		22	20	20.	38 47.
(<i>c</i>)	VI.	10.		16	14	22.	115 32.
		20.		0	42	4.	117 46.
		35.		0	19	44.	29 41.
(<i>d</i>)	I.	33.		11	57	26.	78 25.
		48.		17	10	46.	107 36.
		213.		12	17	59.	44 45.

150th, 756th of the 2d (*a*), and the 18th, 140th, 725th of the 3d (*b*), without any hesitation, till we find ourselves brought to an object such as the nebula in Orion, where we are still inclined to remain in the once adopted idea, of stars exceedingly remote, and inconceivably crowded, as being the occasion of that remarkable appearance. It seems, therefore, to require a more dissimilar object to set us right again. A glance like that of the naturalist, who casts his eye from the perfect animal to the perfect vegetable, is wanting to remove the veil from the mind of the astronomer. The object I have mentioned above, is the phænomenon that was wanting for this purpose. View, for instance, the 19th cluster of my 6th class (*c*), and afterwards cast your eye on this cloudy star (*d*), and the result will be no less decisive than that of the naturalist we have alluded to. Our judgement, I may venture to say, will be, that *the nebosity about the star is not of a starry nature.*

But, that we may not be too precipitate in these new decisions, let us enter more at large into the various grounds which induced us formerly to surmise, that every visible object, in the extended and distant heavens, was of the starry kind, and collate them with those which now offer themselves for the contrary opinion.

			h.	'	"		°	'	"
(a)	II.	12.	RA.	12	32	37.	PD.	72	23.
		150.		14	19	52.		81	43.
		756.		14	51	42.		35	22.
(b)	III.	18.		12	41	7.		84	51.
		140.		1	5	8.		92	0.
		725.		12	6	57.		43	14.
(c)	VI.	19.		15	5	2.		110	14.
(d)				3	56	48.		59	50.

It has been observed, on a former occasion, that all the smaller parts of other great systems, such as the planets, their rings and satellites, the comets, and such other bodies of the like nature as may belong to them, can never be perceived by us, on account of the faintness of light reflected from small, opaque objects; in my present remarks, therefore, all these are to be intirely set aside.

A well connected series of objects, such as we have mentioned above, has led us to infer, that all *nebulæ* consist of stars. This being admitted, we were authorized to extend our analogical way of reasoning a little farther. Many of the *nebulæ* had no other appearance than that whitish cloudiness, on the blue ground upon which they seemed to be projected; and why the same cause should not be assigned to explain the most extensive *nebulosities*, as well as those that amounted only to a few minutes of a degree in size, did not appear. It could not be inconsistent to call up a telescopic milky way, at an immense distance, to account for such *phænomena*; and if any part of the *nebulosity* seemed detached from the rest, or contained a visible star or two, the probability of seeing a few near stars, apparently scattered over the far distant regions of myriads of sidereal collections, rendered *nebulous* by their distance, would also clear up these singularities.

In order to be more easily understood in my remarks on the comparative disposition of the heavenly bodies, I shall mention some of the particulars which introduced the ideas of *connection* and *disjunction*: for these, being properly founded upon an examination of objects that may be reviewed at any time, will be of considerable importance to the validity of what we may advance with regard to my lately discovered *nebulous* stars.

On June the 27th, 1786, I saw a beautiful cluster of very small stars of various sizes, about 15' in diameter, and very rich of stars (*a*). On viewing this object, it is impossible to withhold our assent to the idea which occurs, that these stars are connected so far one with another as to be gathered together, within a certain space, of little extent, when compared to the vast expanse of the heavens. As this phænomenon has been repeatedly seen in a thousand cases, I may justly lay great stress on the idea of such stars being connected.

In the year 1779, the 9th of September, I discovered a very small star near ϵ Bootis (*b*). The question here occurring, whether it had any connection with ϵ or not, was determined in the negative; for, considering the number of stars scattered in a variety of places, it is very far from being uncommon, that a star at a great distance should happen to be nearly in a line drawn from the sun through ϵ , and thus constitute the observed double star.

The 7th of September, 1782, when I first saw the planetary nebula near ν Aquarii (*c*), I pronounced it to be a system whose parts were connected together. Without entering into any kind of calculation, it is evident, that a certain equal degree of light within a very small space, joined to the particular shape this object presents to us, which is nearly round, and even in its deviation consistent with regularity, being a little elliptical, ought naturally to give us the idea of a conjunction in the things that produce it. And a considerable addition to this argument may be derived from a repetition of the same phænomenon, in nine or ten more of a similar construction.

(*a*) RA. 18 h. 20' 2". PD. 107° 3'.

(*b*) Phil. Trans. Vol. LXXII. p. 115. Catalogue of Double Stars, I. 1.

(*c*) RA. 20 h. 52' 36". PD. 102° 12'.

When I examined the cluster of stars, following the head of the great dog (*a*), I found on the 19th of March, 1786, that there was within this cluster a round, resolvable nebula, of about two minutes in diameter, and nearly of an equal degree of light throughout (*b*). Here, considering that the cluster was free from nebulousity in other parts, and that many such clusters, as well as many such nebulae, exist in divers parts of the heavens, it appeared to me very probable, that the nebula was unconnected with the cluster; and that a similar reason would as easily account for this appearance as it had resolved the phenomenon of the double star near ϵ Bootis; that is, a casual situation of our sun and the two other objects nearly in a line. And though it may be rather more remarkable, that this should happen with two compound systems, which are not by far so numerous as single stars, we have, to make up for this singularity, a much larger space in which it may take place, the cluster being of a very considerable extent.

On the 15th of February, 1786, I discovered that one of my planetary nebulae (*c*), had a spot in the center, which was more luminous than the rest, and with long attention, a very bright, round, well defined center became visible. I remained not a single moment in doubt, but that the bright center was connected with the rest of the apparent disk.

In the year 1785, the 6th of October, I found a very bright, round nebula, of about $1\frac{1}{2}$ minute in diameter (*d*). It has a large, bright nucleus in the middle, which is undoubtedly

	h.				°	
(a) RA.	7	32	1.	PD.	104	18.
(b)	7	32	5.		104	15.
(c)	17	58	25.		23	22.
(d)	3	30	35.		109	15.

connected

connected with the luminous parts about it. And though we must confess, that if this phænomenon, and many more of the same nature, recorded in my catalogues of *nebulæ*, consist of clustering stars, we find ourselves involved in some difficulty to account for the extraordinary condensation of them about the center; yet the idea of a connection between the outward parts and these very condensed ones within is by no means lessened on that account.

There is a telescopic milky way, which I have traced out in the heavens in many sweeps made from the year 1783 to 1789 (*a*). It takes up a space of more than 60 square degrees of the heavens, and there are thousands of stars scattered over it: among others, four that form a trapezium, and are situated in the well known nebula of Orion, which is included in the above extent. All these stars, as well as the four I have mentioned, I take to be intirely unconnected with the nebulosity which involves them in appearance. Among them is also *d* Orionis, a cloudy star, improperly so called by former astronomers; but it does not seem to be connected with the milkiness any more than the rest.

I come now to some other phænomena, that, from their singularity, merit undoubtedly a very full discussion. Among the reasons which induced us to embrace the opinion, that all very faint milky nebulosity ought to be ascribed to an assemblage of stars is, that we could not easily assign any other cause of sufficient importance for such luminous appearances, to reach us at the immense distance we must suppose ourselves to be from them. But if an argument of considerable force should now be brought forward, to shew the existence of a luminous matter, in a state of modification very different from the con-

(*a*) RA. from 5 h. 15' 8'' to 5 h. 39' 1'. PD. from 87° 46' to 98° 10'.

struction of a sun or star, all objections, drawn from our incapacity of accounting for new phænomena upon old principles, will lose their validity.

Hitherto I have been shewing, by various instances in objects whose places are given, in what manner we may form the ideas of connection and its contrary by an attentive inspection of them only: I will now relate a series of observations, with remarks upon them as they are delivered, from which I shall afterwards draw a few simple conclusions, that seem to be of considerable importance.

To distinguish the observations from the remarks, the former are given in italics, and the date annexed is that on which the objects were discovered; but the descriptions are extracted from all the observations that have been made upon them.

October 16, 1784. *A star of about the 9th magnitude, surrounded by a milky nebulosity, or chevelure, of about 3 minutes in diameter. The nebulosity is very faint, and a little extended or elliptical, the extent being not far from the meridian, or a little from north preceding to south following. The chevelure involves a small star, which is about $1\frac{1}{2}$ minute north of the cloudy star; other stars of equal magnitude are perfectly free from this appearance (a).*

My present judgement concerning this remarkable object is, that the nebulosity belongs to the star which is situated in its center. The small one, on the contrary, which is mentioned as involved, being one of many that are profusely scattered over this rich neighbourhood, I suppose to be quite unconnected with this phænomenon. A circle of three minutes in diameter is sufficiently large to admit another small star, without any bias to the judgement I form concerning the one in question.

(a) RA. 5 h. 57' 4''. PD. $96^{\circ} 22'$.

It

It must appear singular, that such an object should not have immediately suggested all the remarks contained in this Paper; but about things that appear new we ought not to form opinions too hastily, and my observations on the construction of the heavens were then but entered upon. In this case, therefore, it was the safest way to lay down a rule not to reason upon the phænomena that might offer themselves, till I should be in possession of a sufficient stock of materials to guide my researches.

October 16, 1784. *A small star of about the 11th or 12th magnitude, very faintly affected with milky nebulosity; other stars of the same magnitude are perfectly free from this appearance.* Another observation mentions 5 or 6 small stars within the space of 3 or 4', all very faintly affected in the same manner, and the nebulosity suspected to be a little stronger about each star. But a third observation rather opposes this increase of the faintly luminous appearance (a).

Here the connection between the stars and the nebulosity is not so evident as to amount to conviction; for which reason we shall pass on to the next.

January the 6th, 1785. *A bright star with a considerable milky chevelure; a little extended, 4 or 5' in length, and near 4' broad; it loses itself insensibly. Other stars of equal magnitude are perfectly free from this chevelure (b).*

The connection between the star and the chevelure cannot be doubted, from the insensible gradation of its luminous appearance, decreasing as it receded from the center.

	h.				
(a) RA.	6	0	33.	PD.	96 13.
(b)	5	30	53.		92 21.

January

January 31, 1785. *A pretty considerable star, with a very faint, and very small, irregular, milky chevelure; other stars of the same size are perfectly free from such appearance (a).*

I can have no doubt of the connection between the star and its chevelure.

October 5, 1785. *A star with a strong bur all around. A second observation calls it a very bright nucleus, with a milky nebulosity, of no great extent. A third suspects the milkiness to belong to more of the same, which is diffused over the whole sweep in that place; but a fourth says, that the milky nebulosity is much stronger than what the nebulous ground, on which the star is placed, intitles it to (b).*

The connection, therefore, between the nebulosity and the star is evident.

January 1, 1786. *A star surrounded with milky chevelure; the star is not central. A second observation calls it affected with a very faint, and extensive, milky chevelure. A third only mentions a star affected with milky chevelure (c).*

As by the word chevelure I always denoted something relating to a center, the connection cannot be doubted.

February 24, 1786. *A considerable star, very faintly affected with milky chevelure. A second observation, much the same (d).*

November 28, 1786. *A star involved in milky chevelure (e).*

	h.				PD.	
(a) RA.	6	54	27.	100°	53.	
(b)	5	25	57.	96	52.	
(c)	5	35	56.	89	50.	
(d)	5	59	4.	96	19.	
(e)	5	57	4.	96	15.	

January

January 17, 1787. *A star with a pretty strong milky nebosity, equally dispersed all around; the star is of about the 9th magnitude. A memorandum to the observation says, that, having but just begun, I suspected the glass to be covered with damp, or the eye out of order; but yet a star of the 10th or 11th magnitude, just north of it, was free from the same appearance. A second observation calls it one of the most remarkable phenomena I ever have seen, and like my northern planetary nebula in its growing state (a).*

The connection between the star and the milky nebosity is without all doubt.

November 3, 1787. *A bright star with faint nebosity. A second observation mentions the star to be of the 9th magnitude, and the faint nebosity of very little extent (b).*

June 11, 1787. *Suspected, stellar. By a second observation it is verified, and called a very small star involved in extremely faint nebosity (c).*

November 25, 1788. *A star of about the 9th magnitude, surrounded with very faint milky nebosity; other stars of the same size are perfectly free from that appearance. Less than 1' in diameter. The star is either not round or double (d).*

March 23, 1789. *A bright, considerably well defined nucleus, with a very faint, small, round chevelure (e).*

The connection admits of no doubt; but the object is not perhaps of the same nature with those which I call cloudy stars.

	h.						
(a) RA.	7	16	28.	PD.	68°	39'.	
(b)	23	11	26.		30	0.	
(c)	17	1	51.		47	26.	
(d)	0	1	57.		18	41.	
(e)	11	12	25.		50	17.	

April 14, 1789. *A considerable, bright, round nebula; having a large place in the middle of nearly an equal brightness, but less bright towards the margin (a).*

This seems rather to approach to the planetary sort.

March 5, 1790. *A pretty considerable star of the 9th or 10th magnitude, visibly affected with very faint nebosity of little extent, all around. A power of 300 shewed the nebosity of greater extent (b).*

The connection is not to be doubted.

March 19, 1790. *A very bright nucleus, with a small, very faint chevelure, exactly round. In a low situation, where the chevelure could hardly be seen, this object would put on the appearance of an ill-defined, planetary nebula, of 6, 8, or 10'' diameter (c).*

November 13, 1790. *A most singular phenomenon! A star of about the 8th magnitude, with a faint luminous atmosphere, of a circular form, and of about 3' in diameter. The star is perfectly in the center, and the atmosphere is so dilated, faint, and equal throughout, that there can be no surmise of its consisting of stars; nor can there be a doubt of the evident connection between the atmosphere and the star. Another star not much less in brightness, and in the same field with the above, was perfectly free from any such appearance (d).*

This last object is so decisive in every particular, that we need not hesitate to admit it as a pattern, from which we are authorized to draw the following important consequences.

	h.			°	
(a) RA.	11	45 12.	PD.	33	43.
(b)	6	58 40.		91	29.
(c)	9	27 22.		30	11.
(d)	3	56 48.		59	50.

Supposing

Supposing the connection between the star and its surrounding nebulousity to be allowed, we argue, that one of the two following cases must necessarily be admitted. In the first place, if the nebulousity consist of stars that are very remote, which appear nebulous on account of the small angles their mutual distances subtend at the eye, whereby they will not only, as it were, run into one another, but also appear extremely faint and diluted; then, what must be the enormous size of the central point, which outshines all the rest in so superlative a degree as to admit of no comparison? In the next place, if the star be no bigger than common, how very small and compressed must be those other luminous points that are the occasion of the nebulousity which surrounds the central one? As, by the former supposition, the luminous central point must far exceed the standard of what we call a star, so, in the latter, the shining matter about the center will be much too small to come under the same denomination; we therefore either have a central body which is not a star, or have a star which is involved in a shining fluid, of a nature totally unknown to us.

I can adopt no other sentiment than the latter, since the probability is certainly not for the existence of so enormous a body as would be required to shine like a star of the 8th magnitude, at a distance sufficiently great to cause a vast system of stars to put on the appearance of a very diluted, milky nebulousity.

But what a field of novelty is here opened to our conceptions! A shining fluid, of a brightness sufficient to reach us from the remote regions of a star of the 8th, 9th, 10th, 11th, or 12th magnitude, and of an extent so considerable as to take up 3, 4, 5, or 6 minutes in diameter! Can we compare it to

the coruscations of the electrical fluid in the aurora borealis? Or to the more magnificent cone of the zodiacal light as we see it in spring or autumn? The latter, notwithstanding I have observed it to reach at least 90 degrees from the sun, is yet of so little extent and brightness as probably not to be perceived even by the inhabitants of Saturn or the Georgian planet, and must be utterly invisible at the remoteness of the nearest fixed star.

More extensive views may be derived from this proof of the existence of a shining matter. Perhaps it has been too hastily surmised that all milky nebulousity, of which there is so much in the heavens, is owing to starlight only. These nebulous stars may serve as a clue to unravel other mysterious phenomena. If the shining fluid that surrounds them is not so essentially connected with these nebulous stars but that it can also exist without them, which seems to be sufficiently probable, and will be examined hereafter, we may with great facility explain that very extensive, telescopic nebulousity, which, as I mentioned before, is expanded over more than sixty degrees of the heavens, about the constellation of Orion; a luminous matter accounting much better for it than clustering stars at a distance. In this case we may also pretty nearly guess at its situation, which must commence somewhere about the range of the stars of the 7th magnitude, or a little farther from us, and extend unequally in some places perhaps to the regions of those of the 9th, 10th, 11th, and 12th. The foundation for this surmise is, that, not unlikely, some of the stars that happen to be situated in a more condensed part of it, or that perhaps by their own attraction draw together some quantity of this fluid greater than what they are intitled to by their situation in it, will, of course, assume the appearance of cloudy stars;

stars; and many of those I have named are either in this stratum of luminous matter, or very near it.

We have said above, that in nebulous stars the existence of the shining fluid does not seem to be so essentially connected with the central points that it might not also exist without them. For this opinion we may assign several reasons. One of them is the great resemblance between the chevelure of these stars and the diffused extensive nebulosity mentioned before, which renders it highly probable that they are of the same nature. Now, if this be admitted, the separate existence of the luminous matter, or its independance on a central star, is fully proved. We may also judge, very confidently, that the light of this shining fluid is no kind of reflection from the star in the center; for, as we have already observed, reflected light could never reach us at the great distance we are from such objects. Besides, how impenetrable would be an atmosphere of a sufficient density to reflect so great a quantity of light? And yet we observe, that the outward parts of the chevelure are nearly as bright as those that are close to the star; so that this supposed atmosphere ought to give no obstruction to the passage of the central rays. If, therefore, this matter is self-luminous, it seems more fit to produce a star by its condensation than to depend on the star for its existence.

Many other diffused nebulosities, besides that about the constellation of Orion, have been observed or suspected; but some of them are probably very distant, and run out far into space. For instance, about 5 minutes in time preceding ξ Cygni, I suspect as much of it as covers near four square degrees; and much about the same quantity $44'$ preceding the 125 Tauri. A space of almost 8 square degrees, $6'$ preceding α Trianguli, seems to be tinged with milky nebulosity. Three minutes

minutes preceding the 46 Eridani, strong, milky nebulosity is expanded over more than two square degrees. 54' preceding the 13th Canum venaticorum, and again 48' preceding the same star, I found the field of view affected with whitish nebulosity throughout the whole breadth of the sweep, which was $2^{\circ} 39'$. 4' following the 57 Cygni, a considerable space is filled with faint, milky nebulosity, which is pretty bright in some places, and contains the 37th nebula of my Vth class, in the brightest part of it. In the neighbourhood of the 44th Piscium, very faint nebulosity appears to be diffused over more than 9 square degrees of the heavens. Now, all these phenomena, as we have already seen, will admit of a much easier explanation by a luminous fluid than by stars at an immense distance.

The nature of planetary nebulæ, which has hitherto been involved in much darkness, may now be explained with some degree of satisfaction, since the uniform and very considerable brightness of their apparent disk accords remarkably well with a much condensed, luminous fluid; whereas to suppose them to consist of clustering stars will not so completely account for the milkiness or soft tint of their light, to produce which it would be required that the condensation of the stars should be carried to an almost inconceivable degree of accumulation. The surmise of the regeneration of stars, by means of planetary nebulæ, expressed in a former Paper, will become more probable, as all the luminous matter contained in one of them, when gathered together into a body of the size of a star, would have nearly such a quantity of light as we find the planetary nebulæ to give. To prove this experimentally, we may view them with a telescope that does not magnify sufficiently to shew their extent, by which means we shall gather all their
light

light together into a point, when they will be found to assume the appearance of small stars; that is, of stars at the distance of those which we call of the 8th, 9th, or 10th magnitude. Indeed this idea is greatly supported by the discovery of a well defined, lucid point, resembling a star, in the center of one of them: for the argument which has been used, in the case of nebulous stars, to shew the probability of the existence of a luminous matter, which rested upon the disparity between a bright point and its surrounding shining fluid, may here be alledged with equal justice. If the point be a generating star, the further accumulation of the already much condensed, luminous matter, may complete it in time.

How far the light that is perpetually emitted from millions of suns may be concerned in this shining fluid, it might be presumptuous to attempt to determine; but, notwithstanding the unconceivable subtilty of the particles of light, when the number of the emitting bodies is almost infinitely great, and the time of the continual emission indefinitely long, the quantity of emitted particles may well become adequate to the constitution of a shining fluid, or luminous matter, provided a cause can be found that may retain them from flying off, or reunite them. But such a cause cannot be difficult to guess at, when we know that light is so easily reflected, refracted, inflected, and deflected; and that, in the immense range of its course, it must pass through innumerable systems, where it cannot but frequently meet with many obstacles to its rectilinear progression. Not to mention the great counteraction of the united attractive force of whole sidereal systems, which must be continually exerting their power upon the particles while they are endeavouring to fly off. However, we shall lay no stress upon a surmise of this kind, as the means of veri-

fyng it are wanting: nor is it of any immediate consequence to us to know the origin of the luminous matter. Let it suffice, that its existence is rendered evident, by means of nebulous stars.

I hope it will be found, that in what has been said I have not launched out into hypothetical reasonings; and that facts have all along been kept sufficiently in view. But, in order to give every one a fair opportunity to follow me in the reflections I have been led into, the place of every object from which I have argued has been purposely added, that the validity of what I have advanced might be put to the proof by those who are inclined, and furnished, with the necessary instruments to undertake an attentive and repeated inspection of the same phænomena.

W. HERSCHEL.

Slough, Jan. 1, 1791.

